Student project report

Determinants of noble crayfish capture success - insights for monitoring applications

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Content

Abstract

Native noble crayfish (*Astacus astacus*) populations in Europe are declining mainly based on the crayfish plague (*Aphanomyces astaci)*. Stocking and establishment of uninfected populations within isolated waterbodies like gravel pit lakes constitutes one of the promising strategies to conserve this highly endangered species. Such management actions require adequate monitoring to detect crayfish populations and to validate stocking success which is commonly done using baited traps. Type of bait and positioning of traps within a water body may significantly influence monitoring outcomes. Littoral structures, substrate density, depth and temperature are known to influence capture success of American crayfish. However, less research has been done on European species. Within three artificial gravel pit lakes in northern Germany where noble crayfish have been stocked in the past, we repeatedly investigated trapping success of different bait types (pellet, salmon meat, and no bait) and their influence on detection rates. Further, microhabitat specific data were collected for each trap and analysed for their impact on catch rates using generalized mixed models. All models best predicting crayfish detection included bait type, temperature, depth, lake ID, and the consecutive fishing day where capture success increased with traps using salmon as bait at warmer waters in shallow areas during the second of three consecutive fishing days. The surrounding microhabitat, soil hardness and trap success of neighboring traps were of less importance for prediction of capture success. Former stocking was successful in two of three pit lakes with a low but self-reproducing population density (total CPUE < 0.2) in one lake and a high population density (total CPUE > 1) in the second lake. The third lake was free of crayfish although intense stocking occurred in the past. Suitability of all three waterbodies was evaluated using a suitability index and did not differ considerably between the lakes apart from predator abundancies. My findings show that salmon meat is a superior bait and that temperature / depth selection positively impacts noble crayfish detection in artificial waterbodies and should be considered when establishing species monitoring plans.

Introduction

The noble crayfish (*Astacus astacus*) is one of the largest aquatic invertebrates in European waterbodies and was commonly abundant in most parts of Europe except for the Iberian Peninsula, the British Isles, Iceland and parts of France and Italy (Hager 2003, Pöckl and Southy-Grosset 2009, Kouba et al. 2014, Chucholl and Brinker 2017). Together with the white-clawed crayfish (*Austropotamobius pallipes*) and the stone crayfish (*Austropotamobius torrentium*), *Astacus astucus* is the only native crayfish species in Germany and it was formerly widely distributed among almost all river systems (Schulz et al. 2009, Kouba et al. 2014). Starting in the end of the 19th century, populations of the noble crayfish began to decline and are nowadays limited to a small number of isolated waterbodies and replacement habitats such as ponds, sand-gravel-clay pits and headwaters (Blohm et al. 1994, Blanke 1998, Schulz 2000, Pöckl and Southy-Grosset 2009). Based on the IUCN red list of endangered species it is listed as vulnerable species with a decreasing population trend (Edsman et al. 2010). In Germany, the status is even worse where these animals are classified as being at risk of extinction as it is the case for Lower Saxony (Bundesamt für Naturschutz 2016).

Noble crayfish population decline has several causes: pollution of waterbodies, introduction of alien crayfish and especially the crayfish plague (*Aphanomyces astaci)* which is lethal for native crayfish species (Haase et al. 1989, Diéguez-Uribeondo and Söderäll 1993, Schulz 2000, Schulz et al. 2009). *Aphanonomyces astaci* is an oomycete which infects crayfish species and is listed as a highly invasive species (Global invasive species database 2020). The spread of the crayfish plague was first recorded in the mid of the 19^{th} century and enhanced by the introduction of non-native American crayfish species which act as a vector for this pathogen (Edgerton et al. 2004, Schulz et al. 2009, LAVES 2011). The loss of former crayfish populations led to an increased stocking of the north American spiny cheek crayfish (*Orconectes limosus*) and later the signal crayfish (*Pacifastacus leniusculus*) (Lodge et al. 2000, Schulz et al. 2009) resulting in a repression of native noble crayfish populations, especially in lotic waterbodies where they once mainly occurred (Blanke 1998). Eradication methods of non-native species populations from lotic waterbodies are existing (Souty-Grosset et al. 2004, Gherardi et al. 2011), however, they are rarely and if, solely in small waterbodies, effective (Schulz et al. 2009).

Noble crayfish are known to have a significant impact on plant and animal community structures within lentic and lotic waterbodies (Abrahamsson 1966, Olsson et al. 2008, Ercoli et al. 2015) and are considered an important native, faunal element in aquatic ecosystems (Bohl 1989, Haase et al. 1989, Kirjavainen and Sipponen 2004, Souty-Grosset et al. 2004, Fena 2009). A good example has been demonstrated by Nyström et al (1991) who showed that noble crayfish reduce the amount of different grazing snail species which had positive impacts on periphyton biomass. Nowadays, non-native crayfish proceed in this ecological niche with divergent repercussions on other biota, such as plants, macroinvertebrates, amphibians and fish (Nyström et al. 1999, Lodge et al. 2000, Mccarthy et al. 2006).

To save this ecologically valuable species and its genetic diversity from extinction, stocking actions in suitable waterbodies are recommended (Šmietana et al. 2004, Taugbøl 2004, Schulz et al. 2009, LAVES 2011). Lotic waterbodies, apart from isolated upper stream sections, are less convenient for stocking purposes due to potential immigrations of non-native crayfish in contrast to lentic waterbodies where potential introduction-pathways are primarily human based (Blanke 1998). Artificial waterbodies, such as detention basins and gravel pit lakes, have been shown to be suitable secondary habitats for reintroductions (Blanke 1998, Pockl 1999), especially if predator densities (e.g. European eel *Anguilla anguilla*) are low (Peduzzi and Füreder 2009). The MaNaKa project which this present work contributes to, aims to identify possible drivers primarily impacting the success of noble crayfish restocking (www.awi.de/forschung/besondere-gruppen/aquakultur/aquakulturforschung/projekte/manaka.html).

Management actions like verification of vital natural populations, stocking or habitat enhancement aim to establish and increase noble crayfish populations and need an efficient and periodical monitoring (Bohl 1989, Blanke 1998, Schulz 2000, Hager 2003, Zimmerman and Palo 2011, Stucki and Zaugg 2011). Standardized official monitoring protocols are not established in Germany, including Lower Saxony (LAVES 2011). In general, different methods for crayfish monitoring are available and can be classified into active and passive methods (Larson and Olden 2016, Ulikowski et al. 2017). The most common passive method for crayfish sampling is the use of baited traps (Westman and Pursainen 1982, Maguire et al. 2004, Price and Welch 2009). Contrary to active methods like visual monitoring during night using flashlights, baited traps can also be applied in deeper and turbid water and can therefore be used in many different habitats and water bodies (Martin et al. 2008, Larson and Olden 2016). Various crayfish traps are available on the market, but all work in a similar way (Bean and Huner 1978, Brown et al. 1989, Larson and Olden 2016, Chucholl and Brinker 2017) - crayfish are drawn towards the trap by an attractant and move into the baited traps during night from which the crayfish can barely escape (Ulikowski et al. 2017) and are collected the following morning. Hence, bait type used in traps and habitat type where traps are placed might be critical factors for the development of a standardized sampling procedure.

Type of bait is known to impact crayfish trapping success and can also be species-specific (Zimmer-Faust and Case 1982, Larson and Olden 2016). Usage of manufactured pellets, fresh fish and animal feeds for cats or dogs have been used in former studies (Bean and Huner 1978, Kutka et al. 1992, Taugbøl et al. 1997, Romaire et al. 2004, Beecher and Romaire 2010). Based on their high economical value a great extent of available literature on bait type performance focused on North American crayfish species (e.g., Bean and Huner 1978, Romaire et al. 2004, Beecher and Romaire 2010). However, precise information of bait effects for the trapping of European crayfish is relatively sparse even though its importance has been highlighted before (e.g. Taugbøl et al. 1997, Latzer and Pekny 2019). Fish and crayfish pellets are among the most commonly used bait for noble crayfish trapping (Abrahamsson 1971, Bean and Huner 1978, Huner et al. 1990, Soderback 1995, Zimmerman and Palo 2011). Studies on differences among various fish species used as bait for European crayfish showed no differences in effectiveness between Coregonids (*Coregonis lavaretus*) and Cyprinids (*Abramis brama*) (Skurdal et al. 1992). Moreover, it was found that fish bait from predatory species such as pike (*Esox lucius*) and perch (*Perca fluviatilis*) performed worse compared to cyprinids (*Abramis brama* and *Rutilus rutilus)* (Taugbøl et al. 1997). Hager (2003) stated that salmonid species are of low attraction for noble crayfish and are thus a less effective bait. This contrasts with the information provided by a local, Lower Saxonian expert with longstanding experience in crayfish monitoring (Röttker 2016, personal communication). Based on his experience Atlantic salmon (*Salmo salaris*) is by far outperforming comparable bait types and has additionally the advantage - based on its marine origin - to be free of crayfish plague spores (*Aphanomyces astaci*).

Waterbodies containing noble crayfish can be large (Fevolden and Hessen 1989, Taugbøl and Skurdal 1992, Erkamo et al. 2010, Larson and Olden 2016), and thus, the number of traps in use for monitoring can become a limiting factor. Knowledge about habitat choice of *Astacus astacus*, particularly in gravel pit lakes, can be crucial to detect and catch the animals (Larson and Olden 2016). It is known that crayfish have certain preferences for different habitat structures within a waterbody (Blohm et al. 1994, Blanke 1998, Peduzzi and Füreder 2009). Crayfish density is highly related to the availability of suitable cover types and soil types (Blohm et al. 1994, Hager 2003, Johnsen and Taugbøl 2008). Aquatic vegetation such as water starwort (*Callitriche palustris)* provides food and shelter and is thus beneficial for crayfish, especially for juvenile individuals (Haase et al. 1989, Hill and Lodge 1994, Blanke 1998). Moreover, substrate preferences are known: plain solid substrates (stones, gravel) are preferred, whereas soft substrate such as mud, peat and sand are avoided by crayfish (Bohl 1989, Blohm et al. 1994, Soderback 1995, Peduzzi and Füreder 2009, Chucholl and Brinker 2017). Dense substrates in the littoral zone such as clay provide crayfish the opportunity to build up their characteristic living holes and are therefore favored over sand and other soil structures where individual caves cannot be built (Blohm et al. 1994, Blanke 1998, Peduzzi and Füreder 2009). Depending on the excavation material, substrate characteristics of pit lakes can vary greatly (Jürging 2014) and these individual lake characteristics, especially with respect to littoral zones are known to be divergent to natural lakes (Gee 1978, Strayer and Findlay 2010, Emmrich et al. 2014). However, scientific research about how bottom substrate might influence crayfish detection in such artificial waterbodies has not been done yet.

Commonly, crayfish live in up to 1.5 m depth and are therefore primarily found in the littoral zones - especially in bigger and deeper waterbodies - (Blohm et al. 1994, Tulonen et al. 2008) even though they can also appear in greater depths up to 40 m (Abrahamsson and Goldman 1970).

Irrespective of numerous literature showing distinct crayfish preferences on microhabitat selection, a scientific evaluation of microhabitat effects on crayfish trapping success in replacement habitats like gravel pit lakes has not been done yet. Theoretically, noble crayfish should show preferences towards dense and diggable substrate structures and hence, traps located in microhabitats with these features should have higher detection rates. In contrast to that, traps located in areas dominated by sand and mud should be visited to a lower extent by noble crayfish. Moreover, traps that are set in areas with a higher amount of potential heterogenic cover for hiding during daytime such as macrophytes, wood and stones should also have higher probabilities of being entered by a crayfish whereas traps that are installed in deep littoral zones of the waterbody should be less visited than traps in more shallow zones.

Catch per unit effort (CPUE) values are known to be an indicator for crayfish population trends and the evaluation of restocking programs (Zimmerman and Palo, 2011). Using noble crayfish and signal crayfish (*Pacifastacus leniusculus*), Erkamo et al. (2010) established an index to evaluate stocking success. CPUE values of zero in two following years show that no population was established, values lower than 0.2 with juvenile age cohorts indicate weak populations. Growing populations show an increase in CPUE values over time but remain below a value of 1. Exploitable populations show increasing CPUE values above 1 over years with reproduced crayfish dominating in the catches. In Lower Saxony, stocking of pit lakes has been done in many gravel pit lakes but stocking success has rarely been evaluated and the status of stocked populations is commonly unknown.

The objective of this study was to experimentally test for trapping success of noble crayfish based on habitat choice and bait type in small gravel pit lakes. This basic and autecological knowledge will be crucial for the development of standardized noble crayfish monitoring protocols and predictability of restocking programs success in replacement habitats. The research questions addressed within this study were:

1) Which type of bait commonly used in traps performs best for noble crayfish monitoring?

2) Which lake habitat characteristics determine trapping success in small artificial lakes?

3) How successful were stocking actions in three selected waterbodies with different habitat characteristics?

Study sites

All lakes sampled within this study are located in the federal state of Lower Saxony, Germany (Figure 1) and owned by fishing clubs which are cooperating with the Angler Association Lower Saxony (Anglerverband Niedersachsen e.V.). The first lake is located close to Dörverden (52°49'34.9"N 9°16'20.8"E) and is an artificial waterbody of 1.23 ha in size that was created to gain sand for a nearby ammunition dump (Table 1). It is a relatively shallow lake with an average depth of approximately two meters and with a shoreline length of approximately 520 meters surrounded by forest and partially agricultural fields. The dominating substrate is sand and during the sampling time it was heavily covered with various submerse macrophyte species. This lake was stocked by the local angling club (Angelverein Dörverden e.V.) with approximately 100 specimen of noble crayfish in 2015 (originating from the aquaculture of Steffen Göckemeyer, Contact: Landwirtschaftskammer Niedersachsen, Geschäftsbereich Landwirtschaft, Freundallee 9 a, 30173 Hannover) and since then, crayfish were regularly seen by anglers. Due to the high abundance of aquatic vegetation, angling pressure in this lake is relatively low (Sven Pfeiffer, personal communication 2018).

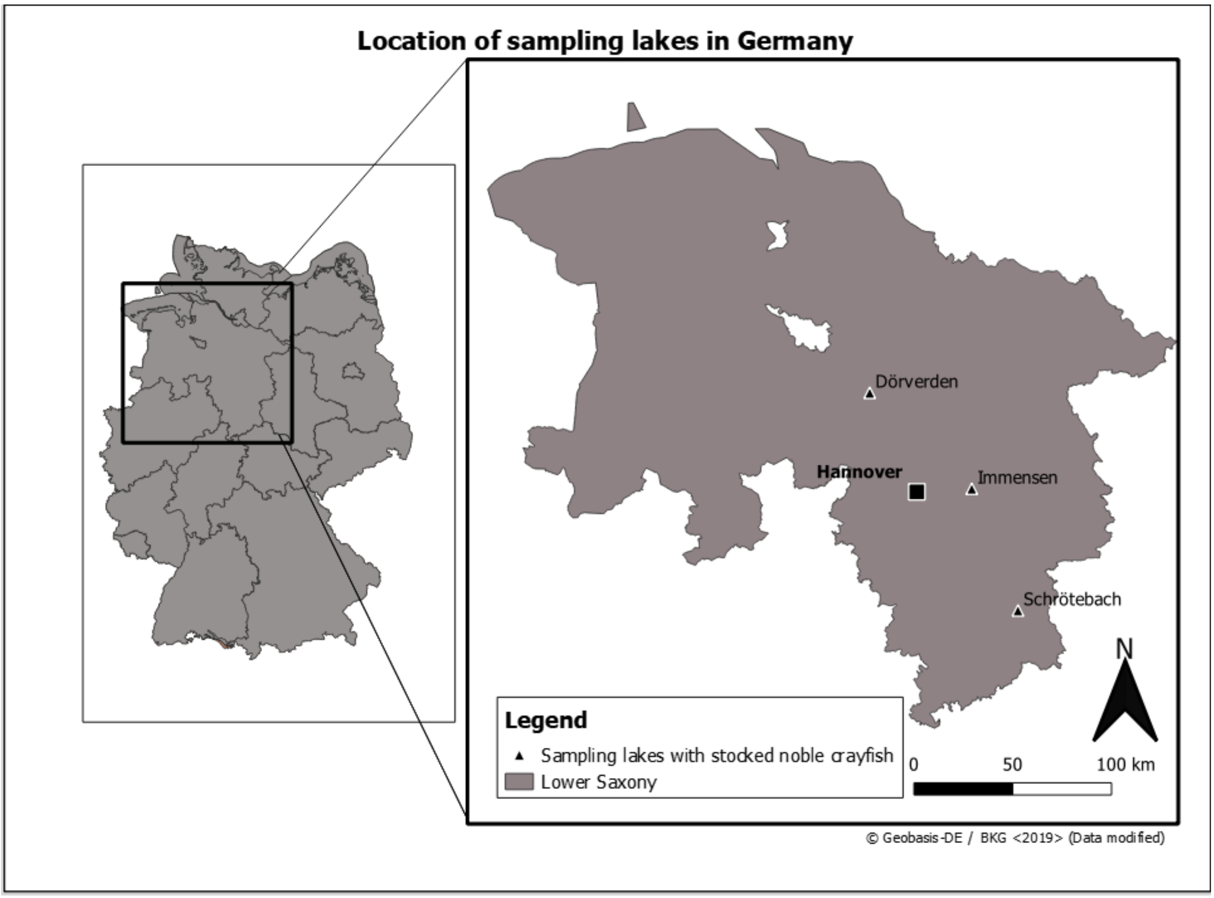

Figure 1 Location of the study lakes in Lower Saxony (Germany)

The second lake is located in the South of the federal state nearby Clausthal-Zellerfeld (51°49'37.7"N 10°21'21.3"E) in a forested area which is managed by the Nordharzer Sportfischer club e.V. It has a total area of 1.44 ha, a shoreline length of 590 m and a mean depth of approximately 3 m (Table 1). This lake is usually stocked with rainbow trout and can be regarded as a put and take waterbody. Information about the exact time when the noble crayfish were stocked into this waterbody are missing. According to the local club members, angling effort at this waterbody is relatively low due to its difficult accessibility.

The third lake is located close to Immensen in the region of Hannover (52°23'08.6"N 10°01'51.4"E). This lake is managed by the fishing club Hannover e.V. and is surrounded by agricultural fields. The average water depth of this waterbody is 4 m and it has an overall area of 5.8 hectares with a shoreline of approximately 1440 m (island shoreline included). This lake was stocked in 2018 with more than 300 individuals of noble crayfish originating from Steffen Göckemeyer (Anglerverband Niedersachsen e.V. 2018) and an electrofishing event in summer 2019 conducted as part of the MaNaKa project revealed dominances of eel and perch (*Perca fluviatilis*) within the littoral area.

Table 1 Different characteristics of the waterbodies sampled within the study

		Lake	
Characteristic	**Dörverden**	**Schrötebach**	**Immensen**
Fishing period	05/28/2018 - 05/31/2018	05/31/2018 - 06/03/2018	06/03/2018 - 06/06/2018
Area in ha	1.23	1.44	5.83
Total shoreline length in m	520	591	1440
Human impact	Fishing – other activities are prohibited	Fishing/Bathing/Dog bathing	Fishing - other activities are prohibited
Surrounding	Forest/Agriculture	Forest/Agriculture	Agriculture

Materials and Methods

Every lake was fished for three consecutive nights. The traps of the Swedish type "Carapaxmjärden" (Carapax Marine Group AB**,** Lysekil, Sweden) (61 cm x 31,5 cm x 25 cm) had two openings with a diameter of 90 x 50 mm and were set using a boat. For each of the three study lakes total shoreline length was estimated using Google earth Pro (including island shoreline).

In the first sampling night, forty traps baited with common pellets of the type "Trappy-Kräftbete™" (Smålandsmjärden AB, Viserum, Sweden) with approximately ten pellets per trap-basket were set randomly with ten traps per cardinal direction along the shoreline, which is the classical sampling approach used in the MaNaKa project.

In the second and third night, traps were separated into three treatment classes: "empty" as a control without bait, "pellet" using 10 pellets "Trappy-Kräftbete™" and "salmon" using 2 cm^2 of defrosted aquaculture salmon filet (*Salmo salaris*) from common supermarkets. A total of three traps per treatment per 100 m shoreline length were set. At least one of the three traps per treatment/100 m shoreline transect was situated at a depth of 0.5 m - the remaining two traps were set randomly in varying depths up to a maximum depth of 5.0 m. Based on the shoreline length, numbers of traps used in the second and third sampling night varied for each lake - with 16 traps/treatment/night in lake Dörverden, 18 traps/treatment/night in lake Schrötebach and 40 traps/treatment/night in lake Immensen. During the trap setup before dusk it was attempted to include all different habitat types present in the lake (macrophytes, sand, wood, coarse particular organic matter dominated (CPOM), stones) including habitats that seemed unlikely to be occupied by the species to avoid bias on the site occupancy probability (MacKenzie and Royle 2005, MacKenzie et al. 2017). The procedure of the second night was repeated in the third night to increase sampling effort and probability of crayfish capture in lakes with potentially low population density. The amount of bait used was kept constant throughout the different sample nights and among all sampled waterbodies. After each sampling night used bait was replaced and bait remainings were discarded in a bucket. For each trap site, coordinates were recorded using a GPS advice (Garmin™, Olathe, Kansas, USA). To detect the nature of the bottom substrate, a long stick (5 m long, 2 cm diameter) was used to identify whether the substrate was soft (> 1 cm and more inundated), medium (<= 1 cm inundated) or rather hard (<= 0.5 cm inundated). Sampling sites were selected a priori to be large enough (about 30 m shoreline length) and to have a reasonable probability that noble crayfish would be present (see MacKenzie et al. 2017). Based on available literature I assumed an average home range for *A. astacus* of about 17 m shoreline length (see Blohm et al. 1994, Hudina et al. 2008, Kadlecová et al. 2012). Moreover, I assumed that the population in the lakes was constant throughout the survey. Traps were lifted the next morning starting at sunrise in the same order they were set.

Captured crayfish were measured for length (ocular-carapace-length to the nearest mm) and weight (wet-weight to the nearest g). Characteristic information about gender, presence of eggs and juveniles, and health status were recorded to gain additional information about the stock state. For each trap set in the second and third sampling night an AESHNA protocol (Brauns et al. 2016), which is commonly used for water framework directive macrozoobenthic organism monitoring, was completed to collect precise data about the surrounding microhabitat (visual assessment). Additionally, oxygen content and temperature were measured with a WTW Multi 350i sensor (164 WTW GmbH™, Weilheim, Germany) device for each 50 cm of the water column at the deepest point of the lake. Chemical water quality based on hardiness, concentration of nitrite/nitrate, ammonium, pH value and conductivity were analyzed using a WaterTest Set Plus (Tetra GmbH, Melle, Germany).

After completion of sampling at each waterbody the boat and all other equipment was disinfected using Wofasteril (Kesla Hygiene AG, Bitterfeld, Germany) in a 5 % solution and afterwards dried in the sun to eliminate the risk of cross infection with crayfish plague between noble crayfish populations. Moreover, lakes with a known existing crayfish population were sampled first to further reduce infection probabilities. Waterbodies with a questionable, existing noble crayfish population were sampled afterwards.

Additional information about each waterbody were sampled based on Peduzzi and Füreder (2009) who created a scheme for noble crayfish waterbodies suitability including habitat and potential predator characteristics. Data collection included substrate heterogeneity, bottom substrate type, shoreline stability, shoreline type, shoreline characterization, littoral substrate, shelter and hideaway distribution, variability of hideaways and abundant predator species as following descriptions in Peduzzi and Füreder (2009). Substrate heterogeneity was assessed as measurement for variability of present substrates, basic substrate type was categorized based on the dominant substrate type and structure availability. Shoreline type was assessed based on dominant shoreline slopes and structures, whereas shoreline characterization was assessed by focusing on the heterogeneity of the shoreline (e.g. structures reaching into the waterbody). Littoral substrate was classified based on its heterogeneity and its potential for crayfish to build lodges. The shelter and hideaway distribution was assessed on the spatial presence and distribution of shelter within the waterbody and the variability of hideaways was assessed based on their heterogeneity and the possibility of separation for different ontogenetic crayfish stages. Data about potential crayfish predators was collected at each lake via sightings and electrofishing data. Data that were impossible to gain or incomplete throughout the sampling season (abundancies of predatory fish in some lakes, general information about fish community composition, waterbody use) were collected by personal communication with local users of the lakes (recreational fisherman, members of the angling association).

Statistics and software

To analyze and compare catch data of noble crayfish between different types of bait and different habitat structures, catch per unit effort (CPUE, number of crayfish caught per trap and per night) values were calculated. For statistical analysis of weight and length between the sexes t-tests were used if data was normally distributed. For not normally distributed population data as well as total lake depended CPUE data, non-parametric Wilcoxon rank sum test statistics were applied. Data of the second and third sampling night were analysed using generalized mixed models and the "glmer" function in library lme4 (Bates et al. 2014) in R. A total of five categorical and two continuous predictor variables were added to the models as fixed effects to describe detection success of noble crayfish (Appendix table 1). Detection of noble crayfish within a trap was coded as 1 and non-detection was coded as 0. Categorical variables consisted of soil hardness (SOI) with levels hard(= 3), medium(= 2), soft(= 1) as a measure of lakebed density, bait type (BAI) with the levels empty (= 1), salmon (= 2), and pellet (= 3), spatially dominating habitat class (HAB) with the levels coarse particular organic material (CPOM) (= 1), wood (= 2), macrophytes (= 3) sand (= 4), and stone (= 5), trap success (SUC) within a 10 meter radius (dummy coded before the modelling progress with 1 for catch in nearby traps and 0 for no catch), lake ID (LID), as well as fishing day (BFT) determining whether it was the second or the third consecutive fishing session in the lake. As continuous variables depth (m) of each trap (DEP) and water temperature (° C) at the position of each trap (TEM) derived from the temperature profile were added to the models. A Pearson correlation test was conducted to identify potential correlations between numerical variables. Trapping date (DAT) was used as a random effect as it was connected to daily changes in weather conditions, which I was not able to account for and which were not in focus of this study. The Nullmodel consisted of the dependent variable (detection success) and the random variable. Models were tested for overdispersion and forward model selection was used to determine the best fitting models explaining crayfish capture. AIC values were corrected for small sample sizes (AICc) as total sample size was small in relation to the total number of estimators included in the model (Burnham et al. 2011) using the R package "AICcmodvag" by Mazerolle (2013). AICc weights were calculated for selected models for further model selection as reported in Wagenmakers and Farrell (2004). A selection of best fitting models with low AICc values was compared using the AICc weight scores and the explained variance was estimated using Nagelkerke´s pseudo R^2. All statistical analyses were conducted using R 3.5.2 (www.r-project.org).

Results

Population status

In total 310 specimen of noble crayfish were caught over three consecutive trapping nights in two of the three lakes (Dörverden = 13 individuals, Schrötebach = 297 individuals) whereas trapping in lake Immensen remained unsuccessful. In lake Dörverden, catches consisted of almost equal gender ratios (Table 2). Most individuals were larger adults (Figure 2). Crayfish size differed significantly between sexes with smaller females and larger males (mean length of females ± SD = 37 ± 5.88 mm and males 44.3 ± 5.61 mm; T-Test, T = - 2.3, P = 0.04). Two females carried almost completely developed juveniles and two females carried spermatophores indicating successful and ongoing natural reproduction in this lake. Animals from lake Dörverden were significantly longer (mean length ± SD = 40.3 ± 6.7 mm) than specimen from lake Schrötebach (mean length ± SD = 35.7 ± 7.34 mm, T-Test, T = 2.44, P = 0.029). Females in lake Schrötebach were significantly smaller (mean length ± SD = 26.8 ± 4.6 mm) than male conspecifics (mean length ± SD = 36.9 ± 7.1mm, Wilcoxon rank sum test, W = 5216.5, P = 0.001). The proportion of females caught during the sampling season was by far higher in Dörverden (46 % of the total catch) compared to lake Schrötebach (7 % of the total catch). In lake Schrötebach two females were carrying eggs/spermatophores indicating natural reproduction also in this lake. Some individuals were in bad condition, other individuals showed heavy algae growth on the cuticula, two individuals were infected by the porcelain disease.

Table 2 Number, mean weight and mean length of crayfish individuals caught in different study lakes

	Catch composition characteristic						
	Number of individuals			**Mean weight in g**		**Mean length in mm**	
Lake	Total	Males	Females	Males	Females	Males	Females
Dörverden	13	6	7	42.6	16.1	44.3	37.0
Schrötebach	297	276	21	28.1	10.7	36.6	26.8
Immensen	0	0	0	0	0	0	0

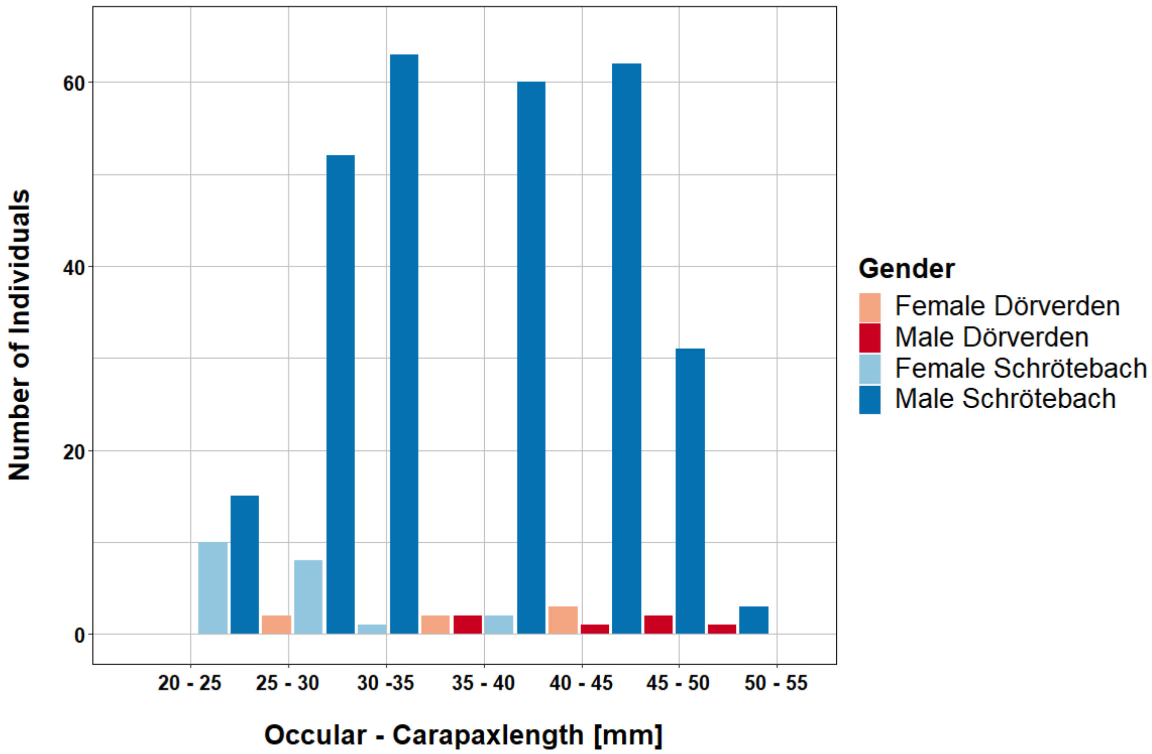

Figure 2 Gender specific length class distribution of *Astacus astacus* in both sampling lakes: red – lake Dörverden, blue -lake Schrötebach

Bait comparisons CPUE values

A total CPUE ± SD over all nights of 0.17 ± 0.34 was estimated for lake Dörverden using 136 traps whereas in lake Schrötebach mean CPUE ± SD over all nights was significantly higher (2.21 ± 2.05, Wilcoxon rank sum test, W = 3269, $p < 0.001$) using 148 traps. Total CPUE values for all intensive sampling nights at both lakes were bait depended. Traps without bait resulted in a CPUE value ± SD of 0.44 ± 0.7 (Figure 3) which corresponds to 15.2 % of all trapped individuals. Catches of traps using salmon as bait resulted in CPUE values ± SD of 1.52 ± 2.01 (52.8 % of all catches) and traps equipped with pellets resulted in CPUE values ± SD of 0.92 ± 1.7 which corresponds to 32 % of the total catch.

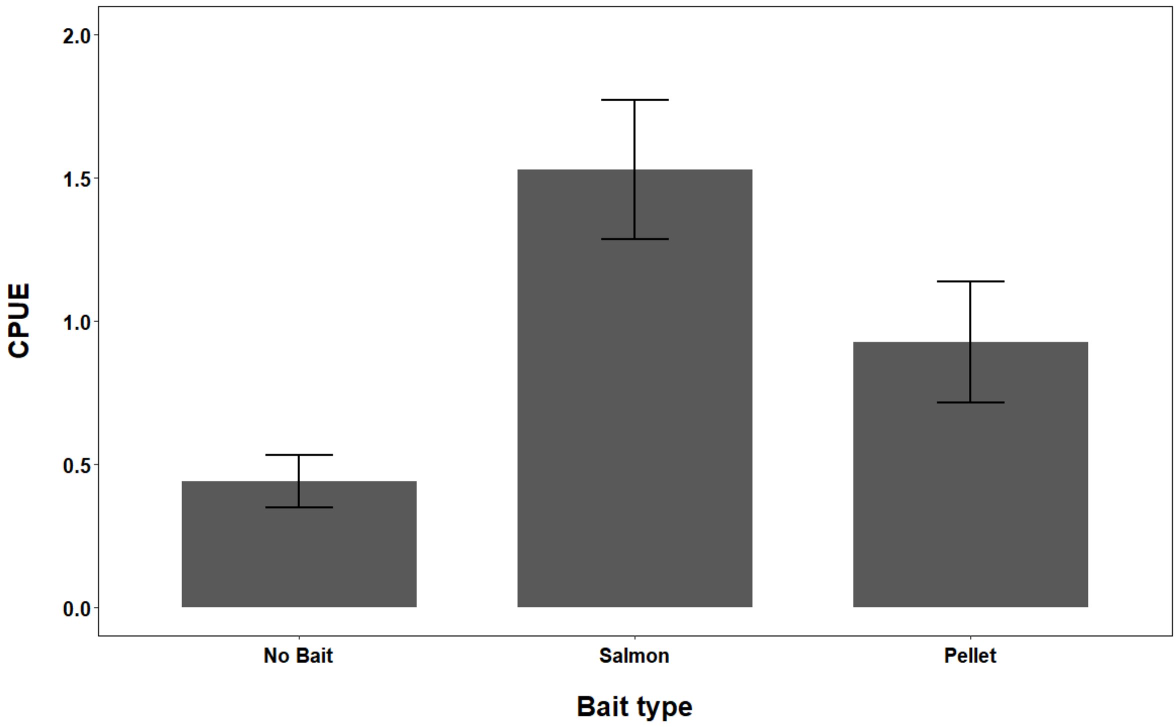

Figure 3 Bait specific CPUE values ± SD for both lakes intensive sampling nights

Generalized mixed model

A Pearson correlation test revealed a slight negative correlation between temperature and depth (Pearsons r value= -0.579, P <0.001) yet both variables were kept as fixed effects for model selection. The best performing model explaining capture success of noble crayfish included lake ID (LID), fishing day (BFT), type of bait (BAI), temperature (TEM) and trapping success of neighbouring traps (SUC) (Table 4) and explained 29 % of the total variance (Table 5). Probability of crayfish capture was highest with salmon as bait in the second or third fishing night with increasing temperature and no capture success with one of the neighbouring traps. The most important variables to predict capture success were bait type, lake ID and day of fishing. This general pattern was confirmed by the second, third, and fourth best models that showed Δ AIC_c < 2 and all contained these three variables, which was also supported by the AIC_c weights. As an example, the AIC_c weights value of the best ranked model (AIC_c weight = 0.34) were 3.7 times higher and thus 3.7 times more likely to be the best fitting compared to the fifth model with an AIC_c weight of 0.09. Against predictions, all measures of habitat type of the traps did not explain capture success indicating that habitat choice of *Astacus astacus* in gravel pit lakes might differ from observations within their natural habitat in streams and rivers (Table 4).

Table 3 Logistic regression of crayfish detection success in small artificial lakes showing the generalized mixed model structure, AIC_c values, Δ AIC_c and AIC_c weights

Model no.	**Model Structure**	**AIC_c value**	**Δ AIC_c**	**$w_i(AIC_c)$**
1	(1|DAT) + LID + BFT + BAI + TEM + SUC	185.73	**0**	**0.34**
2	(1|DAT) + LID + BFT + BAI + DEP + SUC	186.81	**1.09**	**0.20**
3	(1|DAT) +LID + BFT + BAI + TEM	186.96	**1.24**	**0.18**
4	(1|DAT) + LID+ BFT+ BAI + DEP	187.30	**1.57**	**0.15**
5	(1|DAT) + LID + BAI + DEP	188.38	2.65	0.09
6	(1|DAT) + LID + BFT + BAI + DEP + SOI	188.76	4.03	0.04
7	(1|DAT)	214.4080	29.42	0.00

Bold values indicate models with the lowest AICc, a delta AIC_c<2 and greatest w_i(AICc).

Table 4 Factors influencing capture success of noble crayfish using traps showing partial logistic regression coefficients (α), standard errors (SE), p values (p), and pseudo R^2 values. Factors include LID (lake ID 2), third fishing day (BFT 3), bait type (BAI 2 = Salmon, BAI 3 = Pellet), temperature (TEM) and trapping success of neighbouring traps (SUC = 1)

Variable	**α**	**SE**	**p**	**Nagelkerkes pseudo R^2**
LID 2	6,263	1,387	**.0001**	**.29**
BFT 3	0,8529	0,3969	**.0316**	
BAI 2	1,5756	0,513	**.0021**	
BAI 3	0,1873	0,4635	.6861	
TEM	0,492	0,2175	**.0237**	
SUC 1	-1,4933	0,902	.0978	

Habitat suitability

The habitat suitability assessment did not reveal major differences in the suitability between the different study lakes. Substrate heterogeneity, substrate type, shoreline type, and littoral substrate are of medium quality for crayfish habitats in Dörverden (Table 5). Shoreline stability, shoreline characterization, the distribution of shelter and their variability are indicators for favorable habitats. Thus, habitat quality in Dörverden can be described as moderate to favorable for crayfish. In combination with abundance of several crayfish predator’s overall suitability has to be evaluated as of moderate quality. Substrate heterogeneity, shoreline type, shoreline characterization, shelter distribution and hideaway variability in lake Schrötebach are of average quality character for suitable crayfish habitats. Thus, the overall suitability of this lake is of moderate quality. However, absence of most important crayfish predators is a favorable characteristic. Habitat features like substrate heterogeneity, shoreline stability, littoral substrate are of moderate suitability in lake Immensen. Shoreline type, shoreline characterization, shelter distribution and variability are indicators for a suitable habitat. The abundance of six different predator species negatively impacts overall suitability of this waterbody, thus total habitat quality is moderate. Detailed description and evaluation of habitat characteristics for each lake can be found in the appendix.

Table 5 Comparison of the studied lakes with important waterbody features from Peduzzi and Füreder (2009)

	Lake		
Parameter	**Dörverden**	**Schrötebach**	**Immensen**
Substrate heterogeneity	medium	medium	medium
Bottom substrate type	muddy/sandy substrate	stone/pebble substrate	muddy/sandy substrate
Shoreline stability	low erosion	no erosion	low erosion
Shoreline type	medium steep	gentle slope dominating	steep
Shoreline characterization	natural heterogenous many trees/structures	artificial, locally structures	natural heterogenous many trees/structures
Littoral substrate	homogenic, but digging of holes possible	homogenic, but digging of holes possible	homogenic, but digging of holes possible
Shelter/Hideaway distribution in the waterbody	distributed in different zones of the waterbody	dominantly distributed in one single zone	distributed in different zones of the waterbody
Variability of hideaways	large variety of shelter, separation of juveniles and adults possible	homogenic - juveniles and adults can be found in the same shelter	large variety of shelter types, separation of adults and juveniles possible
Abundant predator species	Eel (*Anguilla anguilla*) Perch (*Perca fluviatilis*) Pike (*Esox lucius*) Carp (*Cyprinus carpio*) Kingfisher (*Alcedo atthis*) Crows (*Corvus corone*)	Rainbowtrout (*Onchorhynchus mykiss*) Kingfisher (*Alcedo atthis*) Crows (*Corvus corone*)	Eel (*Anguilla anguilla*) Perch (*Perca fluviatilis*) Pike (*Esox lucius*) Carp (*Cyprinus carpio*) Rainbowtrout (*Onchorhynchus mykiss*) Crows (*Corvus corone*)
Final valuation	moderate	moderate	moderate

Evaluation of stocking success

Based on the catch data in lake Dörverden stocking was successful, females showed signs of reproduction and juvenile were found. High crayfish densities with females showing signs of successful reproduction indicate stocking success of earlier stocking in lake Schrötebach. In lake Immensen no crayfish were recorded at all, indicating a failure of former stocking success.

Discussion

Bait and habitat effects

We compared different bait types frequently used for crayfish monitoring and found that salmon as bait in traps significantly increased detection probability of noble crayfish followed by pellets which also had a positive, however, weaker effect on crayfish detection. Baitless crayfish traps had the least effect on detection probability. Crayfish preferences towards certain types of baits are known and well studied for American crayfish (Romaire and Osorio 1989, Romaire et al. 2004, Larson and Olden 2016). For European waterbodies comparisons are scarce or showed no clear bait effects (e.g. Skurdal et al 1992, Zimmerman and Palo 2011, Latzer and Pekny 2019). My findings are contrary to some studies claiming that pelleted manufactured baits are more effective than fish baits (e.g. Rach and Bills 1987, Romaire and Osorio 1989). However, based on a study on Procambaroid crayfish, harvest baits consisting of clupeid fish species, menhaiden (*Brevoortia tyrannus*) and shad (*Alosa sapidissima*) as well as carp (*Cyprinus carpio*), are favored by crayfish (Romaire et al. 2004). Bait effects can be impacted by water temperature, the time baited traps remain in the water and the bait quantity used (Larson and Olden 2016). Fish used as bait can result in higher catches than commercially produced feeds (e.g. pellets), when the water temperatures are below 21° C (Beecher and Romaire 2010). Contrary to that, pelleted feeds are reported to outperform fresh fish baits when the temperatures are above 24° C (Romaire et al. 2004, Beecher and Romaire 2010). The observed temperatures during my study varied between the lakes and ranged between 12,2 and 24,2° C depending on the trap location and depth. Independent of these highly varying temperatures salmon was by far the most effective bait for monitoring in gravel pit lakes as previously reported (e.g. Bills and Marking 1988, Rötker pers. communication 2016). In contrast to the results of Hager (2003) who reported a lower overall attractivity of salmonids used as bait, my results indicate high capture probabilities of *Astacus astacus* with salmon used as bait over a wide temperature gradient in different water bodies.

During my sampling, implemented bait was removed after each sampling night, and thus, a fresh bait-quality was always warranted which could have favored the short-term effectiveness of salmon meat. Concerning the time, that traps are immersed in the water, Huner et al. (1990) stated that fish used as baits might obtain a higher bait attractivity for short term use due to higher levels of attractants, whereas formulated baits have longer lasting allurement over a prolonged period. However, in common monitoring actions traps are usually emptied after each sampling night and used baits are supposed to be replaced after each use, as old baits are reported to be avoided by the crayfish (e.g. Hager 2003, Hofmann 1980, Romaire et al. 2004). Furthermore, some researchers found evidence that bait quantity positively impacts the crayfish CPUE (e.g. Beecher and Romaire 2010). Thus, the amount of baits, even though it was kept on a standardized level in this study, could have also impacted the results. However, Romaire and Osario (1989) who did trials on bait types and quantities could not find significant effects within the comparison of different amounts of baits used. Equally long soaking times and standardized bait quantities which are realistic to monitoring situations, resulted in salmon being a more reliable bait in my study. Consequently, when sampling objectives are focusing on presence absence information salmon baits can be assumed to outperform pellets and should be considered as common bait in monitoring programs of *Astacus astacus*.

Increasing water temperature was one of three main parameters that predicted capture success of crayfish in traps. As poikilothermic animals, temperature plays an important role for activity (Crawshaw 1974, Hofmann 1980, Abrahamsson 1983, Somers and Green 1993, Sint and Füreder 2004) during ontogenesis (e.g. Westin and Gydemo 1986, Jones 1995), population fluctuations (Olsson et al. 2009) and moreover, in the general species distribution pattern of the noble crayfish (e.g. Weinländer and Füreder 2012). Temperatures above 15° C are important for this species´ reproduction and growth (Bohl 1989, Hager 2003, Bohl 2011) with an optimal summer temperature for crayfish growth lying between 18° C and 24° C (Blanke 1998). Moreover, crayfish catches are known to be affected by water temperature (Ackefors 1999). Increasing water temperatures lead to higher crayfish catches, whereas colder water temperatures result in generally lower catches (Abrahamsson 1983, Somers and Stechey 1986, Somers and Green 1993, Richards et al. 1996, Faller et al. 2006). The average temperatures during the sampling varied in dependence of lake and water depth between 12.2° C and 24.2° C which is within the temperature range of *A. astacus* and thus was an influencing factor in the models predicting crayfish vulnerability.

Crayfish traps in this study were all placed within the shallow littoral of the lakes but even within this narrow depth range we found evidence for a slightly negative correlation between depth of traps and temperature. Shallower areas with warmer temperatures were more often visited by crayfish than those in deeper areas of the waterbodies, which is also consistent with research on other crayfish species (Abrahamsson 1983, Harper et al. 2002, Litvan et al. 2010). A study on adult individuals of *A. astacus* by Tulonen et al. (2008) in pond experiments showed that most of the animals were observed within a 0 - 105 cm water depth range, demonstrating the importance of shallow habitats for this species which is consistent with other authors findings (Ackefors 1999, Bohl 1999). Furthermore, Abrahamsson (1966) reported that shallow worthwhile littoral zones are primarily inhabited by competitive, well-conditioned males, whereas smaller males and females were more often caught in deeper and thus less attractive habitats. However, it has to be noticed that trap catches are mainly based on the activity of the target species, as deeper, colder zones tend to lower activity levels in crayfish (e.g. Abrahamsson 1983). Catch ratios can also be considered lower due to lower animal activity which is not necessarily meaning that those areas are void of crayfish (Ackefors 1999). Pit lake morphology differs from that of natural lakes in a way that they are predominantly deeper (Miller et al. 1996, Castro and Moore 2010) with steep shores (Gee 1978, Strayer and Findlay 2010) resulting in steeper and less structured littoral zones (Emmrich et al. 2014). Considering this lake morphology, favorable habitats for crayfish are limited, leading to higher concentrations of individuals within this zone and potentially explaining higher catch rates in warmer shallow zones within this study.

There was no statistical evidence for an impact of the different sampled microhabitat types on the detection rates of noble crayfish using traps. Habitats providing shelter from predation are reported to inhabit high densities of crayfish in contrast to open and less structured areas (Abrahamsson and Goldman 1970, Bohl 1999, Sint and Füreder 2004). Thus, well-structured habitats offering shelter by macrophytes, roots, deadwood and big stones are favored by noble crayfish (Westman and Pursainen 1982, Bohl 1999, Hager 2003, Johnsen and Taugbøl 2008, Tulonen et al. 2008). One possible reason for divergent results in this study might be based on intraspecific competition within crayfish populations for their favored habitats within the littoral zone that were highly limited so that some individuals were forced to inhabit less preferred habitats as a trade-off in habitat choice between microhabitat structure and depth/temperature. Whereas the waterbody in Dörverden showed plenty of varying structures throughout the fished transects which offered potential shelter for the crayfish, this was not the case in lake Schrötebach, explaining inconsistencies of crayfish habitat choice. Because crayfish were only found in two lakes that highly differed in habitat structure, increasing sample sizes by evaluations of noble crayfish habitat choice and trapping success in more lakes might emphasize different results so that no effects of sampling habitat found in this study should be taken with caution.

Substrate density did not add to the factors explaining detection success of noble crayfish in this study which is consistent with Litvan et al. (2010). Generally, substrate properties are known to be of importance for noble crayfish. Faller et al. (2006) showed that sites in streams with great variability in substrate material resulted in greater catches compared to others. In lakes however, rocky shores tend to be hosted by high densities of crayfish and lower numbers of noble crayfish are found on soft substrates (Soderback 1995). Moreover, loamy substrates are also favored by the crayfish as they provide opportunities for the setup of living-holes (Westman and Pursainen 1978, Haase et al. 1989) contrary to soft, muddy and sandy substrates (Hager 2003). As pit lakes were originally created to provide different substrate materials such as sand, gravel, and clay the dominating lakebed substrate can strongly vary between lakes based on their origin (Kraft 1984). Thus, substrate was strongly influenced by general lake characteristics and lake specific substrate heterogeneity was not varying to such an extent that clear patterns of its impact on crayfish detection could be identified.

Population status

Only two lakes within this study were inhabited by specimens of the noble crayfish with different densities whereas the third waterbody was void of crayfish albeit stocking activities some years before. In lake Dörverden a total of 13 crayfish were captured, all in vital condition and only a few individuals showed signs of missing extremities, which is known as an indicator for dense populations (Abrahamsson 1966, Sint and Füreder 2004). Furthermore, the catches consisted of almost equal numbers of males and females and individuals were also relatively long and heavy compared to the individuals of the dense population in lake Schrötebach, where a total of 297 animals were caught indicating resource limitation displayed by impaired growth and higher mortality rates (Hager 2003). Erkamo et al. (2010) compared the stocking success of different waterbodies via CPUE values. When applied here, Dörverden with a low CPUE value (< 0.2) but different cohorts in the catches can be considered a weak population, whereas the population in Schrötebach can be classified as an exploitable and thus self-sustaining population based on CPUE values above 1. However, it has to be considered that the number of juveniles in lake Schrötebach was low and both waterbodies were fished only once within three consecutive days so that longer monitoring intervals might lead to different results. In addition, lake Dörverden was stocked in 2013 so that the population might not yet be fully developed as catch rates in newly stocked noble crayfish populations in lakes are known to need 4 - 12 years before they reach CPUE`s above 1 (Erkamo et al. 2010). In lake Immensen, no crayfish were caught indicating a very low density or diminished population. As reported by Martin et al. (2008) small populations with low densities in larger waterbodies might often remain undetected or solely detected by chance as the number of traps might not be high enough. In contrast, effort within this study was high (280 traps over three consecutive nights), increasing the chances of detecting even small populations with very low numbers of individuals so that disappearance of stocked crayfish seems to be likely.

Sex ratios differed in the two study lakes that contained noble crayfish with almost equal gender distribution in one lake (Dörverden) and males dominating in the catches in lake Schrötebach. Mean lower numbers of females in comparison to the high catch numbers of large adult males has been reported to be based on aggressive behavior and intersexual competition, especially occurring in unexploited populations (Abrahamsson 1966, Haase et al. 1989, Ackefors 1999, Hager 2003, Maguire et al. 2004, Dorn et al. 2005, Faller et al. 2006, Ogle and Kret 2008, Latzer and Pekny 2019). However, sex ratios of crayfish are naturally equally distributed even though the presence of females in traps is varying seasonally, explaining sex-ratio differences in captures over seasons and between water bodies (Hudina et al. 2008, Nowicki et al. 2008). It can thus be assumed that female numbers were underrepresented in the catches in lake Schrötebach as a consequence of a sex-selective passive fishery because both populations were not otherwise exploited.

The low numbers of smaller individuals in both study lakes might be based on different effects. First, numbers of juveniles in unexploited dense populations are known to be shaped by cannibalism of aggressive males (Abrahamsson 1966). Second, based on gear effects (large trap openings and mesh size) trapping was highly size-selective (Stuecheli 1991, Huner and Espinoza 2004, Stancliffe-Vaughan 2015). Martin et al. (2008) used similar traps and reported an underrepresentation of individuals smaller than 6 cm total length based on the mesh size of the traps. Thus, low abundancies of small individuals (smaller than 20 mm ocular-carapace-length) can be considered sampling effects and likely not a lack of reproduction.

Various authors have observed crayfish escaping from traps, especially during daytime (Westman et al. 1978, Ogle and Kret 2008, Ulikowski et al. 2017). In our study, an escape from traps was unlikely because traps were lifted after sunrise as soon as possible so that differences in catch rates between lakes should reflect true differences in population density. However, based on lake size, trap recovery in lake Immensen took longer than in the other and smaller lakes and in lake Schrötebach high densities of crayfish might have led to a higher tendency of escaping (e.g. Smith and Price 1973, Ulikowski et al. 2017), both potentially lowering CPUE values. Because traps were set for three consecutive nights, a capture and escape of a single individual in lake Immensen seems to be unlikely and in lake Schrötebach, multiple collections during the night might have increased CPUE values (e.g. Hager 2003, Ogle and Kret 2008) but were not conducted for reasons of standardization.

Another aspect that might have influenced results was timing of sampling throughout the year. Field work was conducted between end of May and beginning of June 2018. As reported in other studies, trapping of crayfish in the end of August to September is most successful (Abrahamsson 1966, Abrahamsson 1983, Blanke 1998, Policar and Kozák 2005) even though it is dependent on waterbody specific temperatures and moulting stages (Westman and Pursainen 1982, Richards et al 1996, Ackefors 1999, Skurdal et al. 2002, Hager 2003). It cannot be ruled out that timing of trapping influenced catch rates in this study but based on highly significant differences between our three study lakes, impacts on main findings seem to be unlikely, particularly because water temperatures reached very high values already early that year.

Generally, the application of different fishing methods could have resulted in more unbiased population data. Among others, Westman and Pursainen (1982) recommend the additional use of electrofishing to determine the abundance of juvenile crayfish, which should be considered carefully as it is directly and indirectly (provoked emigration behavior) harmful for the animals (Bohl 1999). Furthermore, SCUBA diving could have been another method for total population assessment (e.g. Taugbøl 2004). Also, the application of a different crayfish trap type (Larson and Olden 2016, Ulikowski et al. 2017) should be considered as an improvement for future studies.

The lakes with known former noble crayfish occurrence varied in their suitability based on various characteristics. Following Peduzzi and Füreder (2009) all three waterbodies had a moderate suitability for crayfish. Predator abundance mainly of perch and eels (Blohm et al. 1994, Blanke 1998, Chucholl and Brinker 2017) is known to play an important negative role in crayfish stock development. Eels were occurring in two of the three lakes where populations did not manage to develop or were only on a weak population level (Erkamo et al. 2010). Particularly in lake Immensen where electrofishing outside of this project was conducted in 2019, eels of all size classes were present, indicating continuous stocking activities and potentially high predation pressure. Thus, a restriction of eel stocking could further increase overall waterbody suitability and lead to higher abundancies (Šmietana et al. 2004).

Conclusions and perspectives

Based on the results of this study project, monitoring programs for the evaluation of stocked noble crayfish populations in gravel pit lakes using common crayfish traps should implement the use of salmon as bait. Salmon was found to be significantly favored by noble crayfish over other type of baits like pellets or unbaited traps. Thus, detection probability of this rare and endangered species can be increased by using optimized baits, thereby minimizing false negative monitoring results, particularly in low abundant populations. In addition, frozen salmon is available all over Europe in almost every supermarket, it is cost effective and based on its marine origin this type of bait can be considered generally free of crayfish plague. Traps should be positioned in shallow and warm water along the littoral zone. Even though specific habitat characteristics increasing capture success could not be identified in this study, structured habitats with submerged vegetation, stones and clay should be covered as they provide shelter for crayfish, potentially decreasing the distance between traps and the target animals. Because capture success decreased with increasing time over consecutive fishing nights, trapping effort should be distributed over several fishing events in summer and early autumn. Decreasing catch rates with increasing fishing effort are well known for interactions of fish and anglers (e.g. Kuparinen et al. 2009) as a consequence of learning and behavioral responses to disturbance (Askey et al. 2006, Klefoth et al. 2013). The same might be true for noble crayfish and these effects can be potentially hindered by fishing breaks of several days or weeks. Crayfish stocking was successful in two of three pit lakes showing their ecological value as secondary refuges for this endangered species. Stocking actions in gravel pit lakes are likely most effective in water bodies with comparably large and well-structured littoral zones and low abundancies of predators like eel, perch, pike (*Esox lucius*) and European catfish (*Silurus glanis*). To ensure reintroduced crayfish populations to sustain it is mandatory to prevent potential crayfish plague introductions into stocked waterbodies (e.g. Chucholl and Brinker 2017). As potential ways for transmitting *Aphanomyces astaci* are plentiful e.g. by contaminated fishing gear or contaminated water (Svoboda et al. 2016, Chucholl and Brinker 2017) it is important inform various user of the waterbody (e.g. anglers) about the potential introduction risks.

Further research might focus on doing standardized pond experiments with different bait types and varying quantity of bait used to yield further information about bait preferences and the respective potential effective range of traps in relation to bait type for lentic waterbodies. Additionally, standardized repeated sampling with differing trap quantities could improve knowledge about the required trap number for positive detection (e.g. Larson and Olden 2016). Present findings are only based on two lakes where noble crayfish were present. Even though the final model gave moderate results which are able to explain about 30 % of the variance, it has to be kept in mind that modelling was based on N = 204 observations of traps containing one or more crayfish individuals. Thus, for more generalized assertions, data collections should be further enlarged with data from different crayfish populations and lakes with broader structural gradients. However, to the best of my knowledge, present data and extent of them are new for monitoring of noble crayfish in pit lakes and can therefore be used as guideline for standardized future crayfish surveys.

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Appendix

Detailed habitat suitability evaluation

Lake Dörverden is mainly embedded in a forest area and thus the riparian zone is near natural with its characteristic vegetation (e.g. *Salix* spec) which can be regarded as positive for crayfish (Peduzzi and Füreder, 2009). The distance to the closest farmland is about 100 meter which is used for corn and cattle production. The overall substrate heterogeneity in Dörverden is medium with sandy and locally muddy substrates. The littoral substrate type is homogenic, however digging of holes is possible which is important for crayfish (Blohm et al. 1994). The shoreline is medium steep with less eroded shore zones. Additionally, installed artificial structures as well as natural structures (e.g. deadwood and macrophytes) are abundant hence a separation of juveniles and adults is possible (e.g. LAVES 2011). According to the members of the local fishing club, eel (*Anguilla anguilla*) was stocked in this waterbody in the past which is known to produce high predation pressure towards crayfish (e.g. Hager 2003). Perch and pike also are abundant in the waterbody and are also listed as predators negatively affecting crayfish populations (Peduzzi and Füreder, 2009). Rainbow trout (*Onchorhynchus mykiss*) has not been stocked in this lake. Moreover, during the sampling potential avian predators – kingfisher (*Alcedo atthis*) and crows (*Corvus corone)* were observed. Additionally, a nutria (*Myocastor coypus*) individual was seen close to traps and in one case remains of crayfish carcasses were found close by the traps. Thus, potential predators are abundant in this waterbody; however the crayfish are able to find enough cover. Habitats for both, juveniles and adults, are abundant which is known to have a positive effect on crayfish (Blanke 1998). In conclusion this lake represents a moderately suitable waterbody for noble crayfish, especially if eel stocking rates are kept moderate or are omitted.

Lake Schrötebach is located close to a forest on one side and on the other side embedded into a pasture. However, the lake shoreline is mainly vegetated by tall herbaceous vegetation which is not a main contributor of leaves which can play an important role in crayfish diet (Blanke 1998, Hager 2003), especially when the amount of submerse macrophytes is low (as observed in this waterbody). The shoreline type can thus be considered as dominantly artificial (Peduzzi and Füreder, 2009). The overall substrate heterogeneity is medium, mainly dominated by pebble and partially sandy muddy/areas which are less favorable for noble crayfish (Blanke 1998). Furthermore, the naturally occurring rock (slate) is creating plane relatively monotonous shore zones underwater. The littoral zone is mainly dominated by gentle slopes that, combined with the substrate nature, does not allow crayfish to dig holes. However, one side of this triangularly shaped like waterbody - the dam - consists of big stones that provide excellent shelter (Blanke 1998, Blohm et al. 1994) where crayfish dens were observed between the stones. Nevertheless, a separation of juveniles and adults does not seem to be possible as the potential shelter is solely concentrated on one side of the waterbody and macrophytes or deadwood is missing, which can lead to intraspecific predation (Abrahamsson 1966). This lake is commonly stocked with rainbow trout and can be suspected as a put and take waterbody. Thus, according to members of the fishing club, pike, perch and eel are not stocked. A potential occurrence of carp cannot be barred. Information about the kingfisher as an avian predator are missing but potential structures (branches above the surface) needed by this species for efficient hunting are missing around the lake resulting in low predation pressure on crayfish. Crows were observed during the sampling at this lake. Thus, the number of potential predators mentioned in Peduzzi and Füreder (2009) is relatively low compared to other waterbodies in this study. The overall properties of this lake are less fitting with those described in the literature as positive for noble crayfish (Blanke 1998, Blohm et al. 1994, Peduzzi and Füreder, 2009) and is evaluated to be moderate.

Lake Immensen is embedded in an area dominated by wheat fields (distance ≥ 15 m) which might have negative impact on crayfish populations due to fertilizer and pesticide discharges (Blanke 1998). Even though there are plenty fishing spots which are cut, natural vegetation is occurring around the waterbody (e.g. angling restricted area, islands – mainly willow) which is favorable for noble crayfish. In three corners reed stands (*Phragmites australis*) are the dominating riparian structure which may serve as a valuable structural element. The overall dominating substrate is sand and locally mud which are less favorable substrates for crayfish (Blohm et al. 1994). The shoreline shows low signs of erosion and is relatively steep. Overall the shoreline can be characterized as being mostly near natural. However, there are plenty of potential shelter types abundant (roots, submerse macrophytes, locally deadwood) and thus a separation between juveniles and adults is possible (e.g. Blanke 1998). This waterbody was used over a long period as a fly fishing only lake and was commonly stocked with rainbow trout. Furthermore, anglers reported catches of adult eel, perch and pike and recent electrofishing revealed high abundances of all size classes of eel and small perch within the littoral. Carps are also abundant in greater numbers and were observed especially in the angling restricted area. Information about the occurrence of the kingfisher is missing, other avian predators such as crows are abundant. The number of potential predators is relatively high; however, potential shelters are also available in greater extent. Lake morphological features are suitable for crayfish restocking but the high numbers of crayfish predators, especially eel and perch, potentially negatively impact *A. astacus* populations and thus, this lake must be considered as of moderate crayfish suitability.

Appendix table 1: Variable specific summary of detection, non-detection and total number of events for each explanatory variable expression

Variable	Expression	N - Detection	N - Non-Detection	N - Total
BAI	BAI1 (no bait)	21	47	68
	BAI2 (salmon)	38	30	68
	BAI3 (pellet)	24	44	68
SOI	Soil1 (soft)	4	19	23
	Soil2 (medium)	12	31	43
	Soil3 (hard)	67	71	138
TEM	12.2	0	3	3
	12.4	0	1	1
	17	3	3	6
	18.4	0	3	3
	19.3	3	0	3
	20.2	23	9	32
	20.3	44	20	64
	20.4	0	4	4
	22	0	19	19
	23.7	0	25	25
	24	3	5	8
	24.2	7	29	36
DEP	0.5	37	41	78
	1	17	13	30
	1.5	12	30	42
	2	11	23	34
	2.5	3	4	7
	3	3	6	9
	4	0	1	1
	5	0	3	3
SUC	0 (no success)	11	61	72
	1 (success)	72	60	132
HAB	1 (CPOM)	9	14	23
	2 (wood)	5	27	32
	3 (macrophytes)	4	29	33
	4 (sand)	3	20	23
	5 (stones)	62	31	93
LID	1 (Dörverden)	10	86	96
	2 (Schrötebach)	73	35	108
BFT	2	34	68	102
	3	45	45	102